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충격 입자 분포 탐지기를 이용한 침식도 추정

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Estimation of Erositivity Using an Impact Disdrometer in East of Alagoas

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요 약

강우는 토양 침식을 일으키는 가장 능동적인 힘 중 하나이다. 다양한 속도와 운동에너지를 가지고 낙하하는 우적은 토양에 충격을 주는 침식력으로 작용한다. 우적의 변동 속도와 운동에너지는 우적의 직경에 직접적으로 의존한다. 이 연구의 목적은 브라질 Alagoas주 Maceió 지역에서 강우에 의한 토양 침식을 산정 할 수 있는 알고리즘을 결정하는 것이다. 이를 위해 1분 간격의 강우 분포를 지속적으로 자동 측정하는 RD-69 디즈드로미터를 사용하여 2003년부터 2006년까지 침식성 강우 자료를 수집하였다. 독립 변수가 강수량인 지수 관계식과 독립 변수가 지속 시간과 최대 강도인 지수 관계식 형태로 최적화된 알고리즘이 결정되었다.

ABSTRACT

Rainfall is one of the most active forces that cause soil erosion. The action of rain on the soil exerts an erosive power caused by the impact of the drops, which fall with variable speed and kinetic energy, depending directly on the diameter of the drop. The objective of this study is to determine algorithms capable of estimating rainfall erosivity for the region of Maceió-AL. For this purpose, erosion rains were collected between 2003 and 2006 using a RD-69 disdrometer, which continuously and automatically measures rainfall distribution in a range of 1 min. The determination of algorithms in the form of power equation to estimate was adjusted with one and two independent variables (amount of rainfall, duration and maximum intensity).

KEYWORDS

Disdrometer, Erosivity, Soil Water Erosion, Soil Degradation, Kinetic Energy
디즈드로미터, 침식도, 토양수 침식, 토양 퇴화, 운동 에너지

Ⅰ. introduction

Erosion is one of the most known types of soil degradation. The Brazilian Society of Soil Science warns that soil degradation is recognized as a risk component for the maintenance of life on the planet[1]. Erosion is a natural process where energy supplied by water, wind and gravity drives

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the detachment, transport and deposition of soil particles[2-5]. Among the several types of erosion, we want to highlight the pluvial-laminar erosion, as it is caused by the removal of the material from the surface of the soil by the water, and its action is accelerated when the soil is unprotected from vegetation.

The Intergovernmental Panel on Climate Change (IPCC) warns of more intense storms, as they will result in higher rates of erosion throughout the land[3]. On a global scale, the risks of soil erosion by water are more restricted between latitudes 40°N and 40°S (tropical and subtropical regions), and rainfall erosivity is 40% in tropical regions[5]. The Ministry of National Integration states that the contribution of rainwater to erosion processes is one of the determining factors for considering the existence of risk to natural disasters in certain areas of the Maceió-AL region[6].

There are few studies on erosivity in Brazil, especially in the northeast[7], Oliveira et al., affirm that there are 73 regression equations to calculate erosivity, but these studies are concentrated in the south and southeast regions of the country[8]. The state of Pernambuco is the one that presents the greatest concern about erosivity in the northeast region. To understand rainfall (impact of droplets) on erosion risky soils in the Maceió-AL region, we chose to analyze the erosive rains using a device called the Joss-Waldvogel disdrometer (JWD), model RD69. This equipment captures information of volume, diameter and kinetic energy of the drop, amount, duration and intensity of precipitation.

This study will becomes relevant, since the physical parameters of rain that are related to rainfall erosion were evaluated in an unprecedented way in the region of Maceió-AL.

II. Materials and Methods

2.1 Data Criteria

Initially, for the calculation criteria of erosion index integrated in 30 min (EI_{30}) were used to select individual erosive rainfall[9-13]. Among the criteria of the different authors, we can highlight:

(i) To study EI_{30} rainfall (Q_c) $\geq$ 10 mm was considered.

(ii) If Q_c < 10 mm, the amount of rain in 15 minutes must be at least 6.0 mm.

(iii) Rainfall separated by less than 6 hours with any amount in this period, or rainfall separated by 6 consecutive hours or more, with 1.0 mm or more of rainfall during this period, should be treated as the sole individual rainfall. Carvalho et al. explain that the minimum and optimal time, defined as the interval between two rains, is a function of the variation of the water infiltration rate in the soil after the end of the first event[10]. This time, definitely suffers alteration with the diverse types of soil.

(iv) At least one segment of intensity is greater than or equal to 25.0 mmh^{-1}.

(v) We disregarded Q_c < 1.0 mm in this period.

(vi) Total kinetic energy ERA (total) is greater than or equal to 360 Jm^{-2}.

2.2 Erosivity

To determine an equation that estimates the erosive potential of rain EI_{30} in $Jmm(m^2h)^{-1}$ from an independent variable, the amount of rainfall Q_c in mm, an approximation was made for power law, in the form. regression analysis was also performed including rainfall the duration D and maximum rainfall intensity $R_{\max}$ as the second independent variable.

$$EI_{30} = \alpha Q_c^a \tag{1}$$

$$EI_{30} = \beta Q_c^b D^c \tag{2}$$

$$EI_{30} = YQ_c^d R_{\max}^e \quad (3)$$

where dependent variable $Y=EI_{30}$, independent variables $X=Q_cD$ and R, a and b are intercept and slope, respectively. To transform the power function $Y=aX^b$ into the linear function we have $\ln y=\ln\alpha+\beta\ln x$ and to obtain the desired results, we must transform the observations X_i in $\ln x_i$ and the observations y_i in $\ln y_i$. With the adjustment of a least squares regression, to compute the coefficients of the regression line as intercept, slope, and the coefficient of determination r^2, we must compute the coefficients α, β and γ doing as a line intercept of the exponential transformation is $\ln\alpha$, to calculate the coefficient, where $A=e^{\alpha}(\ln A=\alpha)$ and $b=\beta$.

2.3 Performance indicators

The comparison between the erosivities calculated from disdrometer data and the estimated from the equations determined by adjustment of the variables were applied calculation of the following statistical indicators: mean absolute error (MAE), root mean square error (RMSE), Willmott's concordance index and confidence or performance index[12].

$$MAE=\frac{\sum_i^n |E_i-O_i|}{n} \quad (4)$$

$$RMSE=\left[\frac{\sum_i^n (E_i-O_i)}{n}\right]^{0.5} \quad (5)$$

$$d=1-\left[\frac{\sum_{i=1}^n (E_i-O_i)^2}{\sum_{i=1}^n \lceil (|E_i-\overline{O_i}|)+(|O_i-\overline{O_i}|\rceil^2}\right] \quad (6)$$

$$c=rd \quad (7)$$

where O_i is the observed value, E_i estimated or approximate value, n numbers of observations, $\overline{O}$ average of observed values, and r correlation coefficient.

Ⅲ. Results and Discussion

3.1 Estimation of Erosivity

According to Wischmeier and Smith, the erosivity index is a statistical interaction term that reflects how total kinetic energy and peak intensity are combined in each individual storm[6]. Both the aforementioned authors, pioneers in the application of this methodology, thus, several national and international researchers conducted works applying these procedures, recommending the determination of a numerical value of the erosivity index from a historical series of rain, because the average value of rain corresponding to a number of years long enough to admit the representation of the predominant mean value of the place where the data were collected. The descriptions related to the index are prominent to explain that the ideal would be to determine for Maceió region or even any other region, using a historical series of rainfall. However, the research proposes to do a preliminary evaluation of the erosivity using a truncated sample of the RD-69 disdrometer. Then, due to the reduced sample, it was not possible to determine the R-factor, however, relationships $EI_{30}-Q_c$ (erosivity index - amount of rain per minute) were determined. This mathematical equation can estimate the numerical value EI_{30} for erosive rain in 24 h.

Equation (8) was adjusted, using as dependent variable EI_{30} and independent variable Q_c were considered a single erosive event with $Q_c \geq 10\ mm$, where EI_{30} is equal to the rainfall erosivity in $Jmm(m^2h)^{-1}$ and Q_c quantity of rain in mm.

$$EI_{30}=2949Q_c^{1.72},\quad r^2=0.89 \tag{8}$$

The regression relation from equation (5), gave a erosion index equation. The amount of rain (Q_c) accounts for 89% of the variability of EI_{30}, indicating a significant linear relationship. The reliability of the regression line was assessed by constructing 95% confidence intervals. Analyzing the F-test of global significance of the model, it is verified that the P-value is less than 0.05, which shows that the variable Q_c is related to EI_{30}.

Evaluating the variable Q_c through the significance test, the independent variable, with 0.045, shows statistical evidence of the relationship between EI_{30}, as the value of Q_c was less than 0.05 within acceptable limit (see Table 1). The determination of the statistical equation to predict rainfall erosivity, based only on rainfall, is therefore quite acceptable. The amount of rain will always remain an approximate (independent) predictor of erosivity and estimation can be expected for low and high amounts of rainfall.

Table 1. Static coefficient values for regression equation using Q_c as independent variable

Predictor	Estimate	Standard deviation	Stat.t	P-value
EI_{30}	7.98	0.075	105.27	0.00
Q_c	1.72	0.045	38.25	0.00

The EI_{30} depends on the amount, the duration of the storm and the maximum intensity of each rain. Thus we determined a second algorithmic regression adjusted. Two independent variables simultaneously used to predict the value EI_{30}. We hope to improve the adjusted determination coefficients, thus decreasing, the prediction error value of EI_{30}. In the second equation, the duration D of each erosive event is the second independent variable with the main variable rainfall Q_c.

$$EI_{30}=1808Q_c^{2.04}D^{-0.71},\quad r^2=0.93 \tag{9}$$

The coefficient r^2 adjusted for multiple regression was 93% in equation (9) with 187 different durations ranging from 30 min to 12 h. The P-value in the F-test of significance was less than 0.05, confirming that at least one of the two independent variables is related to EI_{30}. Analyzing the individual statistical significance of the parameters Q_c and D, and only D, through the standard deviation, the independent variables showed evidence of being related to EI_{30}, 30, since their values were greater than 0.05 in Table 2. The regression equation with two independent variables has good significance, and is adequate for predictions. Thus, as adjusted r^2, F-test and standard deviation of the variables (dependent and independent) are good measure how well the equation fits the sample data.

Table 2. Values of the static coefficients for regression equation with two variables

Predictor	Estimate	Standard deviation	Stat.t	P-value
EI_{30}	7.54	0.084	89.63	0.00
Q_c	2.04	0.052	39.12	0.00
D	-0.71	0.076	-9.25	0.00

In order to test the rainfall variables, a third equation adjusted with two independent variables, besides rainfall, was replaced by the maximum rainfall intensity $R_{\max}$ in mmh^{-1}, as the second predictor variable.

$$EI_{30}=159Q_c^{0.95}R_{\max}^{1.26},\quad r^2=0.95 \tag{10}$$

The adjusted coefficient of determination for this multiple regression was 95%. In equation (10) we used 187 rain intensities ranging from 1.32 mmh^{-1} to 73.47 mmh^{-1}. Equation (10) established an F-test of significance greater than 0.05, shown that the variable Q_c and $R_{\max}$ are related to EI_{30}. In Table 3 we can analyze the independent significance of the independent variables in the standard deviation. Both Q_c and $R_{\max}$ show statistical evidence since their values were greater than 0.05.

Table 3. Static coefficient values for regression equation with two variables

Predictor	Estimate	Standard deviation	Stat.t	P-value
EI_{30}	5.07	0.19	26.57	0.00
Q_c	0.96	0.05	18.64	0.00
$R_{\max}$	1.26	0.08	16.58	0.00

3.2 Evaluation of the erosivities

The analysis of the performance of the equations determined in this study was performed by comparing the values of EI_{30} calculated from the data of the disdrometer, and those estimated by the equations adjusted in the form of power. Among the algorithms that determine the approximate value of EI_{30}, equation (10) was the one that presented better performance indicators, contrary to equation (8) that presented higher values (Table 4).

The smaller the difference between observed and estimated, the better the measurement accuracy. The agreement index (d), proposed by Willmot, has this property ($0 \leq IC \leq 1$) and can be used, for example, to compare different simulations of the same phenomenon[14]. The determined equations presented high values for Willmott's coefficient and similarly for the analysis of the reliability of the equations, we considered the confidence index (c) proposed by Camargo and Sentelhas, being that the equation (10) was the one that presented values closer to 1, for the three determined equations[15]. The concordance and confidence index was considered optimal.

Table 4. Indicators of the performance of equations determined to estimate EI_{30}

Equations	EAM	RMSE	d	c
Eq. (8)	103.42	436,524.38	0.99	0.93
Eq. (9)	134.80	411,763.56	0.99	0.95
Eq. (10)	44.07	174,663.76	0.99	0.97

Table 5 shows the reliability of the estimates made by equations (8), (9) and (10). It was necessary to calculate the confidence intervals (ϵ) in the estimated erosivity. The approximate confidence interval in the form $Y \pm t(1-\alpha)s$ where Y is equal to rainfall $t(1-\epsilon)$ is the value of the distribution T-student, with the 90% confidence interval[16].

IV. Conclusions

Rainfall data that reached the region of Maceió-AL were collected by an impact disdrometer from 2003 to 2006. From the analysis of the erosivity and rainfall erosion index, the following conclusions were noted, as a preliminary point:

1. Erosive rainfall with $Q_c \geq 10$ mm, $E_{RR(total)} \geq 360\ Jm^{-2}$, and with at least one rainfall of R $\geq 25\ mmh^{-1}$ was considered. This type of rainfall was observed in almost every month during the period of the study, except between October and December, drier months of the year with lower rainfall indices. The month of July had more occurrence of erosive type rain, justified for being part of the rainy season in the region. The chances of erosive rains occurring during the rainy season of the region are higher, however, this does not prevent erosion rainfall that can occur in the driest period. Erosive rains can occur at any time of the year, but the chances of occurring in the rainy season are bigger.

Table 5. Reliability analysis of the rain erosivity estimate

Equations	Interval (Dependent variables)		Estimated
	Q_c (mm)		$EI_{30} \pm \epsilon$
	0.02 - 0.99		749.33 ± 1,226.54
	1.02 - 1.96		5,205.94 ± 6,256.03
$EI_{30} = 2949 Q_c^{1.72}$	2.01 - 2.93		13,162.31 ± 14,611.96
	3.14 - 7.83		38,670.69 ± 53,858.73
	8.13 - 13.51		145,647.67 ± 176,948.70
	14.35 - 73.63		910,545.02 ± 1,782,766.52
	$Q_c(mm)$	$D(\min)$	$EI_{30} \pm \epsilon$
	0.56 - 2.27	10 - 15	334.51 ± 815.78
	0.16 - 7.83	16 - 29	789.79 ± 1,619.55
$EI_{30} = 1808 Q_c^{2.04} D^{-0.71}$	0.14 - 9.43	30 - 44	115.41 ± 3,143.38
	1.42 - 16.59	45 - 57	3,554.37 ± 12,638.21
	0.80 - 23.41	61 - 89	1,011.14 ± 8,156.54
	2.23 - 73.36	91 - 700	1,113.83 ± 34,003.26
	Q_c (mm)	$R(mmh^{-1})$	$EI_{30} \pm \epsilon$
	0.09 - 0.99	1.33 - 16.11	931,55 ± 1,788.29
	1.02 - 1.82	3.24 - 30.52	6.235,63 ± 8,816.59
$EI_{30} = 159 Q_c^{0.95} R_{\max}^{1.26}$	1.84 - 2.61	7.02 - 54.82	16.057,53 ± 23,738.81
	2.61 - 4.05	7.43 - 49.51	25.736,59 ± 35,431.82
	4.16 - 9.89	12.03 - 62.10	99.041,50 ± 134,725.95
	10.40 - 58.69	20.28 - 73.47	381.641,96 ± 648,435.03

2. For this first evaluation, the months with higher and lower erosivity are June and September, respectively, with 4,934,181.98 $Jmm(m^2h)^{-1}$ and 899,323.25 $Jmm(m^2h)^{-1}$. The highest values are associated with higher rate and amount of rainfall and higher amount of total kinetic energy of each rain event. The climatic condition of the region influences the greater or lesser possibility of occurrence of erosive rains. Of the erosive rains that reached the region of Maceió during the study period, 47% occurred during the rainy season.
3. The rate and amount of kinetic energy of the rain, therefore, the erosivity of the rain is directly related to the size and quantity of drops, this will also imply the amount and intensity of the rain during its evolution.
4. The amount of rain Q_c accounts for 89% of the variability of EI_{30}, indicating a significant linear relationship. Evaluating variable Q_c through the significance test, the independent variable with 0.045 shows statistical evidence of the relationship between EI_{30}, as the value of Q_c was less than 0.05 within acceptable limit.
5. The second algorithm used two predictor variables to predict the value EI_{30}, includes in addition to the amount of rain Q_c, the rain duration D was entered as the second independent variable. The coefficient of r^2 adjusted for multiple regression was 93%. The individual statistical significance of the parameters Q_c and D, through standard

deviation, show evidence of relationship between the independent variables with EI_{30}.

6. For the third algorithm to estimate EI_{30} was adjusted with two variables, amount of rain Q_c and maximum intensity $R_{\max}$. The adjusted coefficient of determination for this multiple regression was 95%. This equation established an F-test of significance > 0.05, shown that the variable Q_c and $R_{\max}$, are related to EI_{30}.

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References

[1] Sociedade Brasileira de Ciência do Solo, 2015, http://www.sbcs.org.br/.

[2] D. J. Holz, K. W. J. Williard, P. J. Edwards, and J. E. Schoonover, "Soil Erosion in Humid Regions", *J. of Contemporary Water Research & Education*, vol. 154, 2015, pp. 48-59.

[3] M. C. Moraes, R. S. Tenorio, E. Sampaio, H. A. Barbosa, C. A. C. Santos, H. J. Yoon, and B. H. Kwon, "Kinetic Energy Rate of the Rain Drops Based on the Impact Signal Analysis", *J. of the Korea Institute of Electronic Communication Sciences,* vol. 14, no. 4, 2019, pp. 734-754.

[4] W. G. Jo, B. H. Kwon, and H. J. Yoon, "Partitioning Bimodal Spectrum Peak in Raw Data of UHF Wind Profiler", *J. of the Korea Institute of Electronic Communication Sciences,* vol. 14, no. 1, 2019, pp. 61-68.

[5] R. S. Tenorio, B. H. Kwon, M. C. Moraes, and H. J. Yoon, "Estimation of Erosion Index Based on Impact Signal Analysis", *J. of the Korea Institute of Electronic Communication Sciences,* In press.

[6] R. K. Pachauri and L. A. Meyer, *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Geneva: IPCC, 2014.

[7] N. W. Hudson, *Soil Conservation.* New York: Cornell University Press, 1971.

[8] P. T. S. Oliveira, E. Wendland, and M. A. Nearing, "Rainfall erosivity in Brazil: A review", *Catena,* vol. 100, 2013, pp. 139-147.

[9] CPRM, "Mapa da Geodiversidade do estado de Alagoas", Companhia de Pesquisa e Recursos Minerais, 2012.

[10] W. H. Wischmeier and D. D. Smith, "Rainfall energy and its relationships to soil loss", *Trans. of the American Geophysical Union*, vol. 39, no. 2, 1958, pp. 285-291.

[11] M. S. V. Cabeda, *Computation of storm EI Values*, West Lafayette: Purdue University Press, 1976..

[12] F. Lombardi Neto, *Rainfall erosivity - its distribution and relationship with soil loss at Campinas Brasil*, West Lafayette: Purdue University Press, 1977.

[13] M. P. E. Carvalho, O. S. Freddiand, and V. Veronese Júnior, "Critérios para classificação de chuva individual erosiva para o Estado de São Paulo", *Acta Scientiarum*, vol. 26, 2004, pp. 175-183.

[14] C. J. Willmott, "On the validation of models", *Physical Geography*, vol. 2, 1981, pp. 184-194.

[15] A. P. Camargo and P. C. Sentelhas, "Avaliação do desempenho de diferentes métodos de Estimate da evapotranspiração potencial no Estado de São Paulo, Brasil", *Rev. Bras. Agrometeorologia,* vol. 5, no. 1, 1997, pp. 89-97.

[16] C. M. Mannaerts and D. Gabriels, "Rainfall erosivity in Cape Verde", *Soil & Tillage Research*, vol. 55, 2000, pp. 207-212.

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